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X-20 WINDOW TESTS

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MURRAY N. ENGLAND

FOREWORD

This report was prepared by the Structures Test Branch, Structures Division, Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The work was accomplished under Project No. 1368 "Structural Design Concepts," Task No. 136802 "Window System Concepts," with Mr. Murray N. England, Project Test Engineer and Mr. Bernard E. Davis, Instrumentation Engineer.

This report covers work conducted from February 1965 through April 1965. The manuscript was released by the author in November 1965 for publication as an RTD Technical Report. This is the final report of the X-20 window structural tests.

This technical report has been reviewed and is approved.

Fred J. Peck Jr

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ABSTRACT

This report describes two structural integrity tests of the X-20A high temperature side window. One test simulated the air leakage from the window during boost and the second test simulated the thermal cycle experienced during reentry. The outside window panel failed prematurely during the thermal cycle, apparently the result of excessive thermal gradients through the frame and a stress concentration caused by thermistor instrumentation leads passing through the frame and under the window seals.

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ILLUSTRATIONS

SECTION I

INTRODUCTION

A series of tests was conducted on the X-20 hot side window assembly consisting of simulating the boost vibration*, the air leakage from the window assembly under the partial vacuum of space, and the thermal cycle experienced during reentry. This report describes the air leakage and reentry heating tests that were conducted by the Structures Test Branch, Structures Division, Air Force Flight Dynamics Laboratory (FDTT). The Boeing Company prepared the test plan report (Boeing Document No. D2-81293), assembled the window, installed the thermistors and data thermocouples, and manufactured the pressure box.

A separate investigation of the light transmission factor through the window before and after heating is discussed in the Appendix.

*AFFDL-TR-65-155, High Temperature Side Window Test Evaluation, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, November 1965.

SECTION II

TEST SPECIMEN AND CONDITIONS

TEST SPECIMEN

The test specimen was a window assembly (Boeing Dwg. 25-86200) which included three flat glass panes, mounting seals and springs, retaining frame, and three point support fittings. A portion of the cab frame, supporting the window frame assembly at three support points, was included to simulate the correct thermal environment.

The three glass panes were constructed of Corning fused silica (Code Number 7940). The two inner panes were coated on all surfaces with an infrared reflective coating; the outer pane was similarly coated, but on the inside surface only. Thermistors were mounted on both sides of all panes. The infrared coating was not used at locations of thermistors and thermistor leads.

The glass panes were supported by a René 41 retaining frame and the edges of the panes were clamped between flanged layers of the retaining frame. Seals made of Hastelloy-X matrix and enclosed in Hastelloy-X foil were used to cushion the glass panes as they were clamped in the frame. The seals were to restrict the flow of plasma (hot air) into the fuselage cavity. René 41 leaf springs were installed in series with the seals to eliminate the slack in the seal system which resulted from relative motion of the assembly when subjected to heat and load. René leaf springs were also used to position and support the panes in the plane of the window.

The René 41 frame was supported at three locations around its periphery by spherical bearings which were gold-plated to reduce friction in their sockets. The bearing assemblies were also designed to permit relative translation of the window frame and the cab frame without inducing resisting forces.

TEST CONDITIONS

Test Condition No. 2, a leakage test, simulated the air leaking through the window seals during the boost environment. Test Condition No. 3, a heat only test, simulated the thermal environment experienced during reentry.

Test Condition No. 1, a boost vibration test, is discussed in AFFDL-TR-65-155.

SECTION III

TEST SETUP AND PROCEDURES

TEST ARTICLE

The test article was shipped to the FDTT Structures Test Facility disassembled, with only the thermistors bonded on the glass; there were no leads attached and no calibration curves. The thermistors were calibrated at FDTT in heat-treatment ovens prior to installation of the glass in the frame assembly.

Assembly of the window in the frame and then into the cab frame, as well as attachment of all data thermocouples and thermistor leads, was accomplished at the FDTT Structures Test Facility by Boeing personnel. Boeing Document No. D2-81293 outlined the procedures to be followed during the test as well as the maximum quantities to be expected for the measured parameters.

TEST EQUIPMENT

Test Condition No. 2

Meriam Laminar Flow Meter Element - Model 50MH 10

Meriam Inclined Manometer - Model 40HE 34

Meriam Mercury Pressure Manometers - Model 338A

Air Temperature Sensor (fabricated by FDTT)

Deflection Transducers (fabricated by FDTT)

FDTT High Speed Data Acquisition System

Test Condition No. 3

Deflection Transducers (fabricated by FDTT)

FDTT High Speed Data Acquisition System

FDTT Heat Rate Computer

TEST CONDITION NO. 2

The test specimen cab frames were to be tied rigidly to a heavy jig and then an air tight pressure box attached to the outside window frame with mylar. The box was then to be evacuated in steps while measuring the air leaking into the box through the window seals. The gap between the outside window and the frame was to be measured before and after the test and deflection information recorded continually during the test. This procedure was followed except that the mylar was replaced with zinc chromate to give a more satisfactory seal. A preliminary test using mylar showed excessive leakage.

Figure 1 is a photograph of the test setup and Figure 2 a schematic of the apparatus for measuring the air leakage. Prior to the test, the vacuum line was capped off at the test specimen, the valve was closed, and the pump shut off to assure there was no leakage.

During the test bleed valve B was closed until the pressure manometers read the correct pressure in the pressure box. The Meriam flow meter indicated the amount of air flowing back to the vacuum pump and thus the amount leaking into the pressure box through the window seals. The flow meter was calibrated to read up to 1.6 SCFM with water in the manometer. When it became apparent the leakage was going to exceed 1.6 CFM, mercury was substituted for the water in the inclined manometer to extend the range.

Following the test, a valve was installed at the test specimen end of the vacuum line and a series of flow versus pressure readings was made with the valve opened to different amounts in order to verify the linearity of the flow meter up to the flow value measured during the test.

TEST CONDITION NO. 3

For test condition No. 3, the specimen was to be tied rigidly to the jig in one place only to allow for thermal expansion. Three temperature profile curves were to be followed: one on the top window, one on the frame and one on the lower dummy aluminum window. Silicon carbide was to be spread evenly over the surface of the top window but not over the thermistors. The silicon carbide was installed to raise the emissivity of the glass to absorb more radiant energy. The gap between the outside window and frame was to be measured both before and after the test and temperatures and deflections were to be recorded continuously during the test. Figure 3 is a photograph of the test setup for condition No. 3, and Figure 4 is a schematic of the X-20 window section locations and tie-down points.

The procedures were followed with the exception that the silicon carbide was removed for the actual test. Efficiency tests conducted prior to the actual test indicated the silicon carbide (installed per Boeing recommendation) caused the glass to heat much too rapidly. It was removed with a vacuum cleaner, which left a small residue. This may have accounted for the glass temperatures being slightly higher than programmed.

Figure 5 shows the upper surface lamp layout and also the location of the four control thermocouples (C_1, C_2, C_3, C_4) and the two fairing thermocouples (F_1 and F_2).

The electrical power applied to the lamps in each control area was determined by the FDTT heat rate computer which matches the actual temperature of the control thermocouple or thermistor with the desired temperature as programmed on a magnetic drum and adjusts heat lamp voltages accordingly. Figure 6 is a schematic of the temperature control apparatus.

SECTION IV

TEST RESULTS

TEST CONDITION NO. 2

The deflections in milli-inches versus time are plotted in Serial No. 203 data which are on file in FDTT. Typical deflection point locations are shown in Figure 7. (See Figure 4 for all locations.) The plotted as well as tabulated data are on file at FDTT.

The large amount of air leakage made it impossible to follow the time curve (see Figure 11 of Boeing Document D2-81293) but the pressure was held constant in steps of 2 psi, per the curve, while the leakage was read as follows:

Pressure (psi)	Leakage (SCFM)
-2	1.029
-4	1.755
-6	2.610
-7	3.10
-6	2.755
-4	1.755
-2	1.040

The window gaps before and after both tests are shown in Figure 8.

TEST CONDITION NO. 3

Two efficiency tests were conducted on the test specimen. A constant voltage was applied to all heat lamps and temperatures from all the thermocouples and thermistors, and all deflections were recorded. These data are on file at FDTT.

Included in the tabular and plotted data under Serial No. 206 are the temperatures and deflections recorded during a run which lasted 80 seconds and was then aborted when the ignitrons malfunctioned. Following this run the specimen was inspected and no damage was observed.

The final test was terminated after 380 seconds when it was observed that the top glass had broken (see Figures 9 through 14). From the data it appears the break occurred after 352 seconds. Only the top glass failed; there was no apparent damage to the rest of the test specimen.

The heat lamps in the control zone directly over the glass and controlled by thermistor No. 1 did not come on. The lower surface lamps designed to heat the aluminum dummy window likewise did not come on. These areas absorbed heat indirectly from (1) the lamps that heated the frame adjacent to the glass, and (2) from the residue of silicon carbide on the top glass which intensified this effect.

The results of the final test are presented in graphical and tabular form under Serial No. 207 on file at FDTT. AFFDL-TR-65-155 also contains the plotted data for this test condition. Plots of representative temperatures and deflections recorded during Test Condition No. 3 are shown in Figures 15 through 21.

SECTION V

CONCLUSIONS

The window cracks appeared to start at the point where the thermistor instrumentation leads entered the window frame.

The failure was caused by excessive bending of the window frame resulting from the high thermal gradient tnrough the depth of the window frame. A stress concentration and a hot spot probably existed where the thermistor leads entered the window frame. This stress concentration would have contributed to the premature failure.

APPENDIX

DETERMINATION OF VISIBLE LIGHT TRANSMISSION FACTOR

INTRODUCTION

In a separate investigation, the light transmission factor of the window assembly was measured before and after heating the window. A device for making this measurement was obtained but found to be inoperative. FDTT instrumentation personnel assembled a device to attempt to obtain readings so the test could continue.

Following the heat test a second set of readings was obtained with a different photoconductor. This was followed by a third set of readings which was obtained using a standard Photo Research Spectra Brightness Spot Meter.

The validity of the readings obtained from the first two setups is questionable because of the lack of information relating current drop to attenuation of light in the visible spectrum.

TEST SETUP AND PROCEDURES

Figure 22 is a sketch of the apparatus made by FDTT and used for the preheat and post-heat measurements. A current reading was made without the window in place (through air). The window was then placed between the light source and the photoconductor and a second reading was made.

Figure 23 is a sketch of the standard apparatus used to make the third set of readings. A series of readings was made with different light intensities through air and then through the window.

TEST RESULTS

Before heat test with FDTT apparatus with RCA 7163 Photoconductor.

Through Air	Through Window	Ratio $\frac{\text{Window in}}{\text{Window out}}$
.210 amps	.125 amps	.595
Light Intensity Increased:		
.280 amps	.165 amps	.589

After heat test with FDTT apparatus with Layfette MS 791 Photoconductor.

Through Air	Through Window	Ratio $\frac{\text{Window in}}{\text{Window out}}$
Light Intensity Increased:		
.770 amps	.490 amps	.636
.245 amps	.142 amps	.580

After heat test with Photo Research Spectra Brightness Spot Meter UB 1/2.

Through Air Ft-Lamberts	Through Window Ft-Lamberts	Ratio $\frac{\text{Window in}}{\text{Window out}}$
1000	650	.65
500	310	.62
240	120	.50
150	100	.67

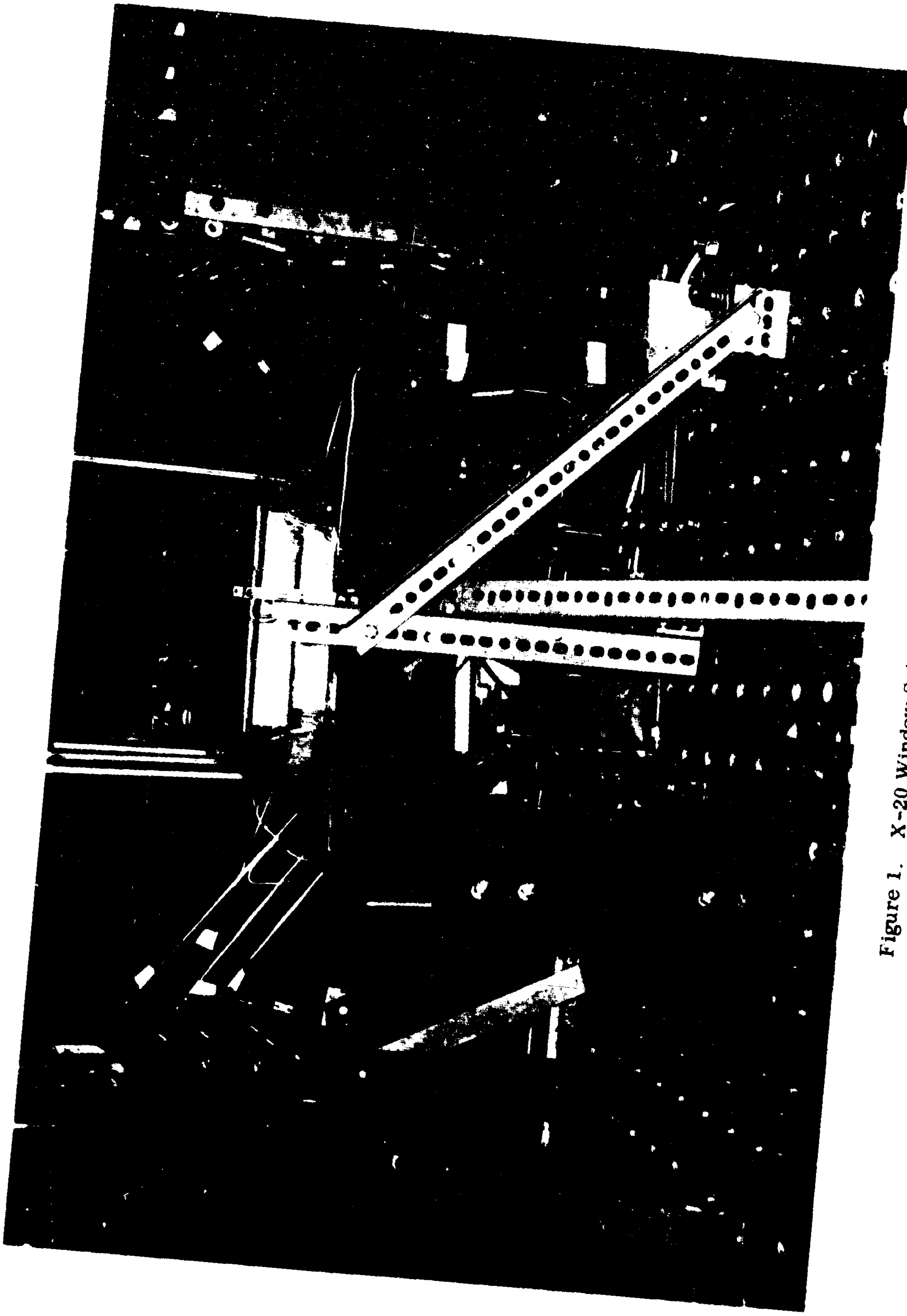

Figure 1. X-20 Window Setup, Test Condition No. 2

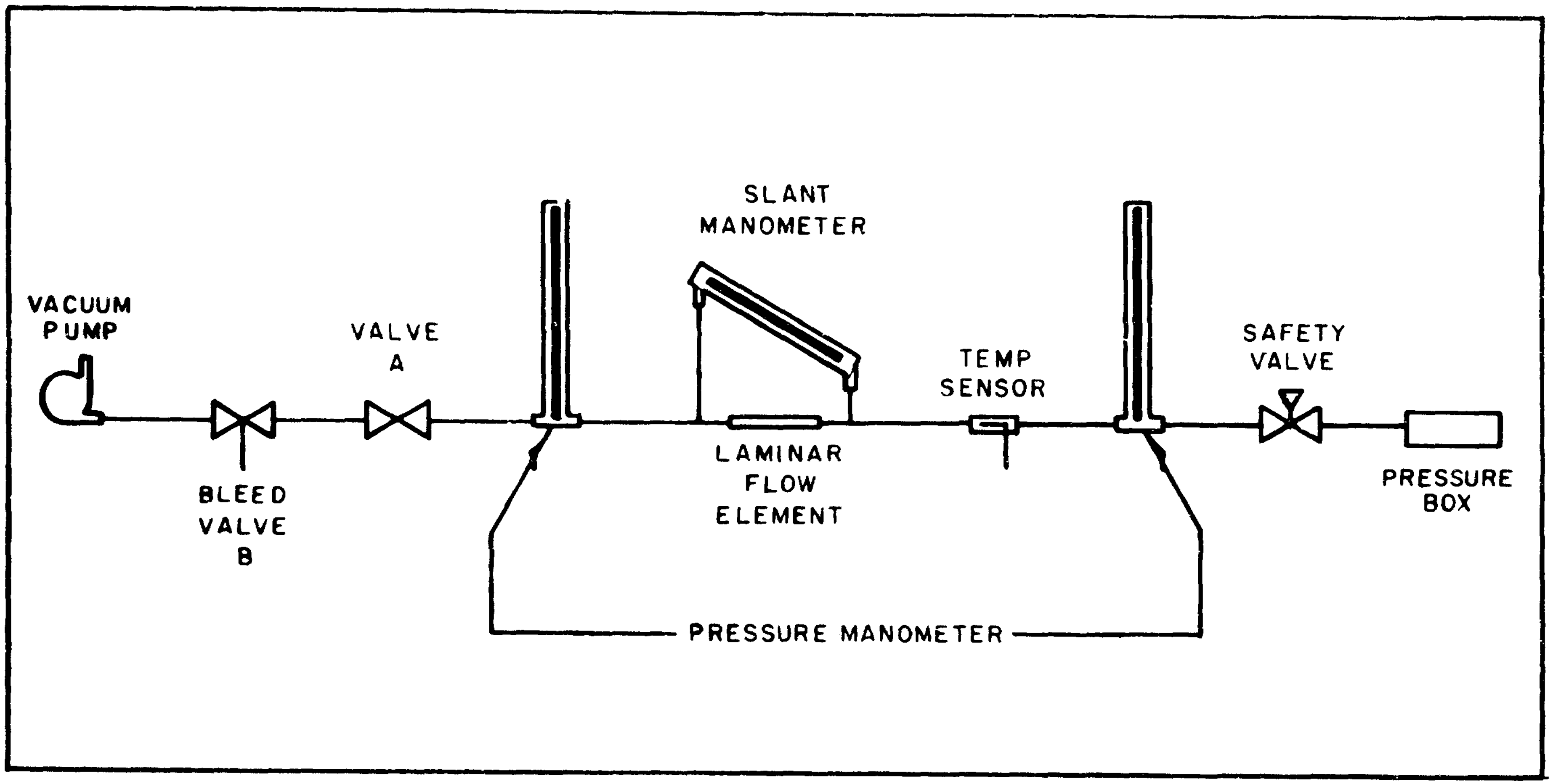

Figure 2. Vacuum System Schematic, Test Condition No. 2

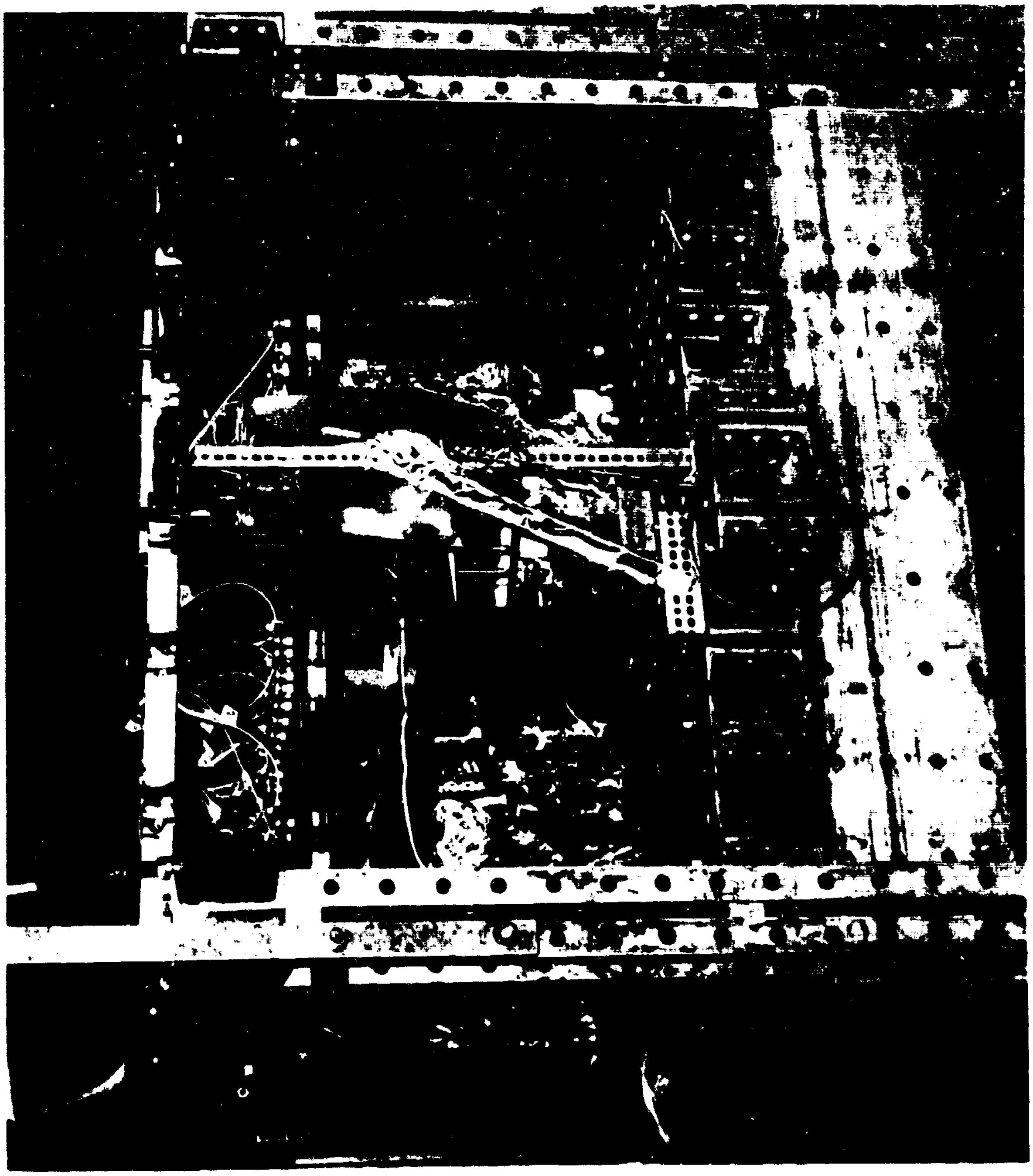

Figure 3. X-20 Hot Side Window Setup, Test Condition No. 3

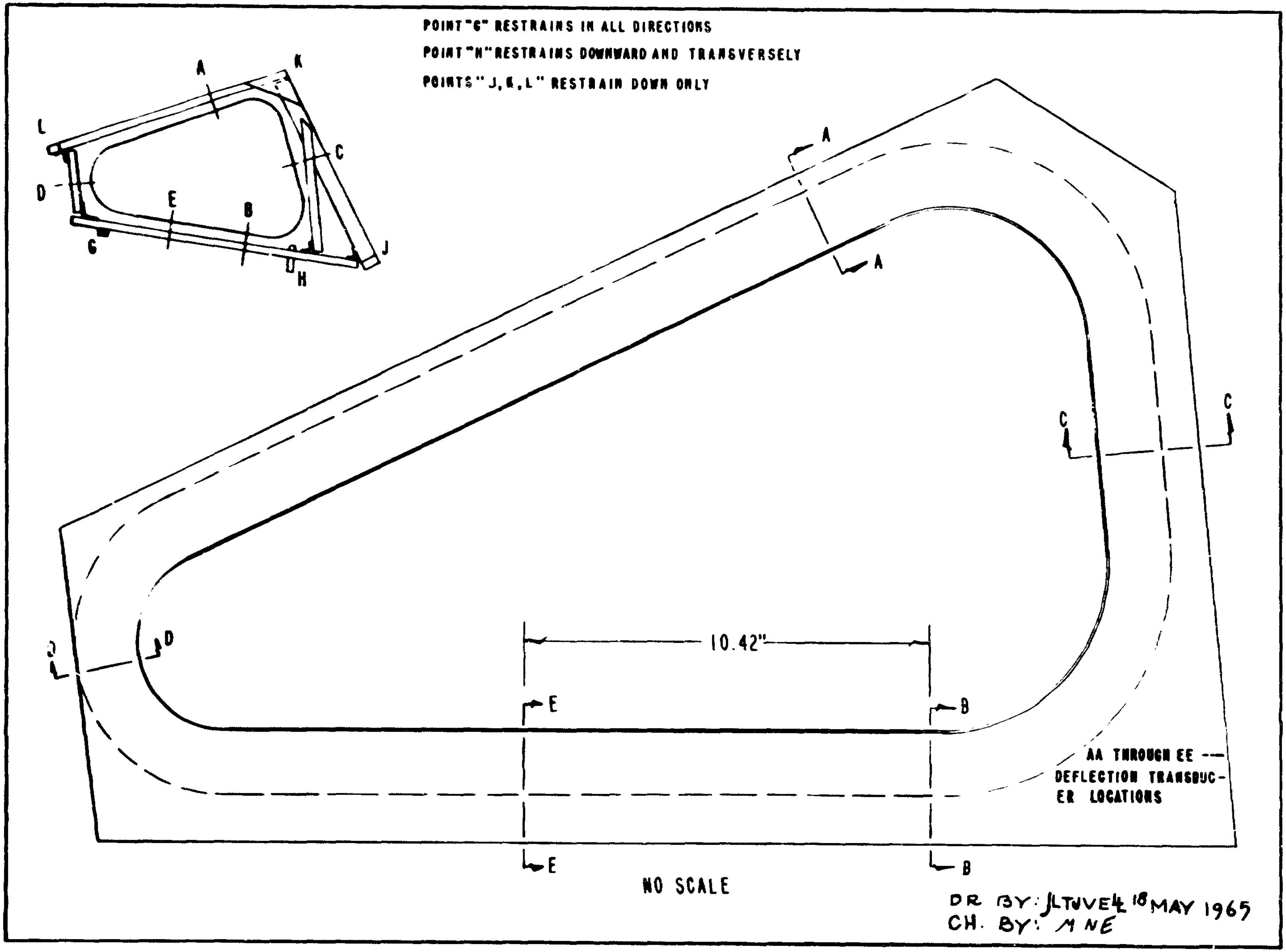

Figure 4. Schematic of X-20 Window Section Locations and Tie-Down Points

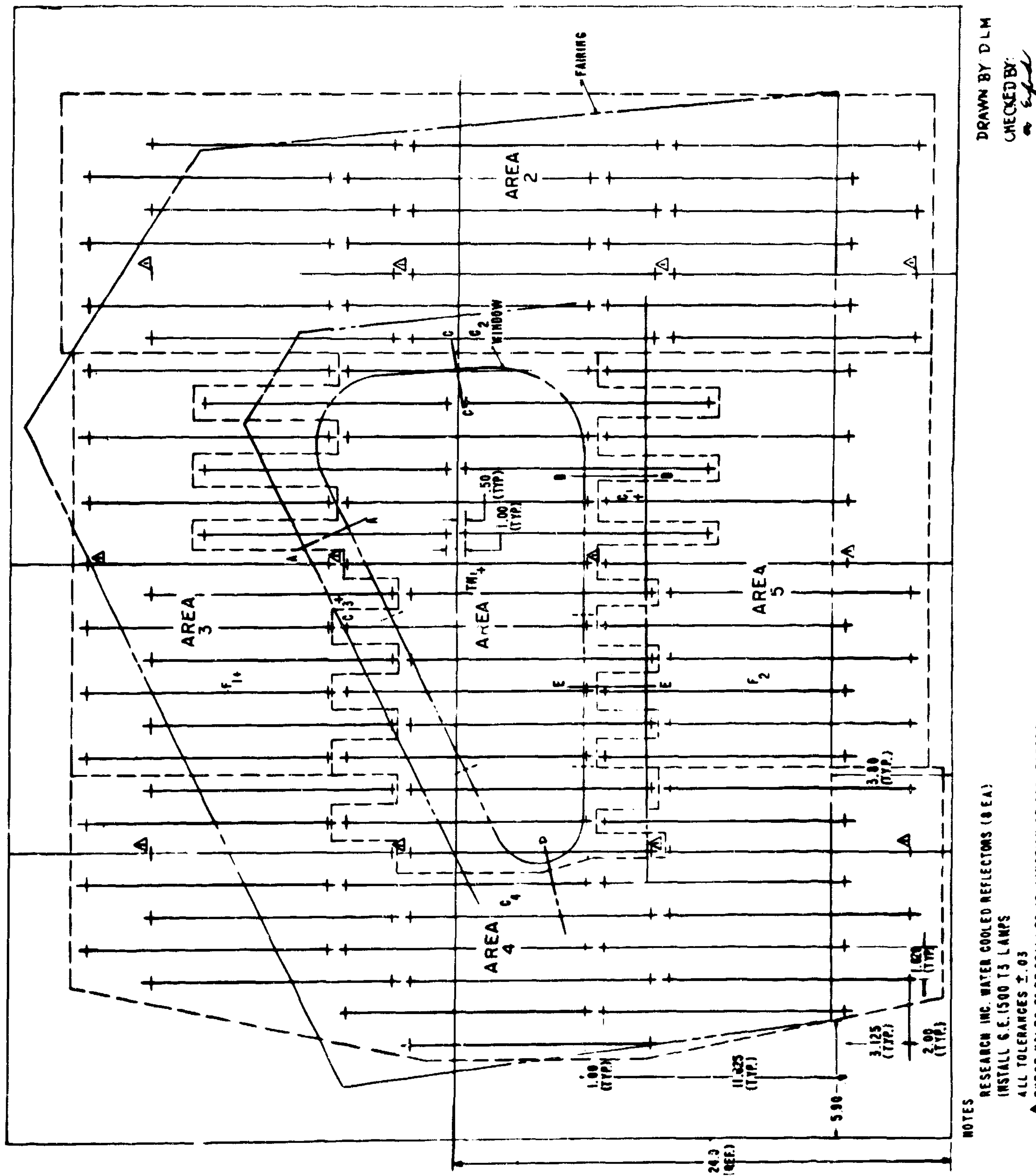

Figure 5. X-20 Hot Side Window Lamp and Area Layout, Test Condition No. 3 (1/2 Scale)

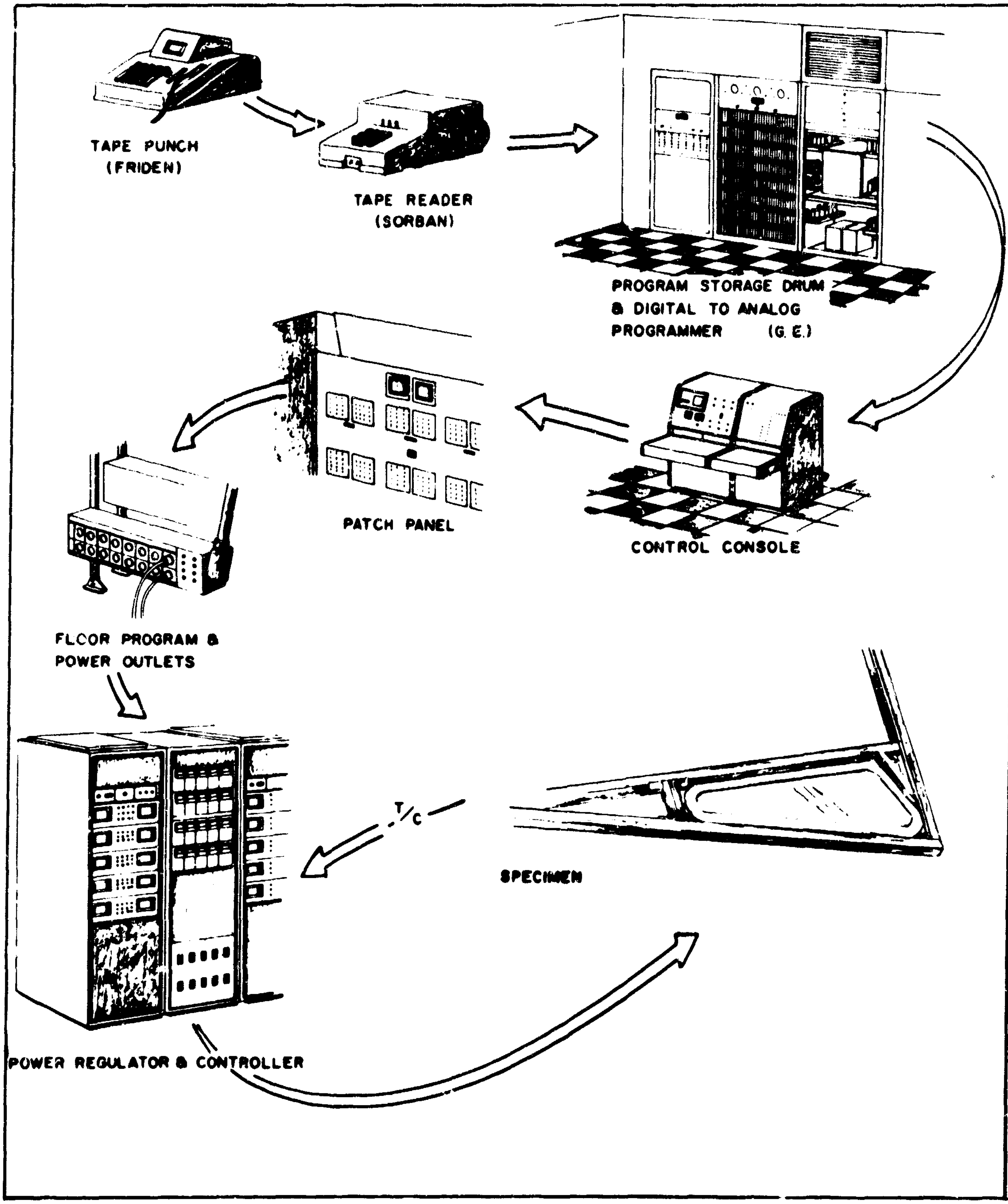

Figure 6. Program Control Circuit

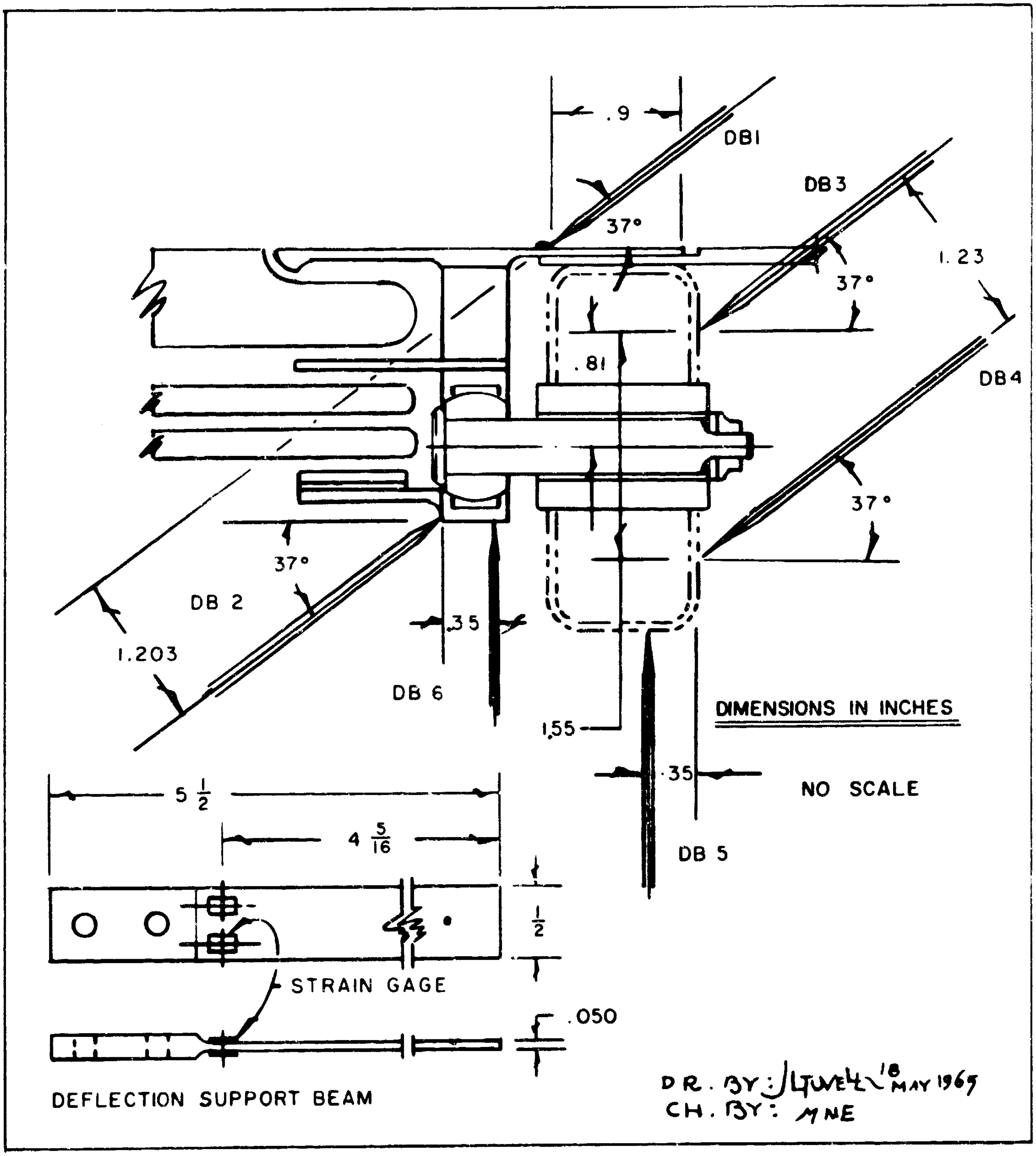

Figure 7. X-20 Window Typical Deflection Point Locations

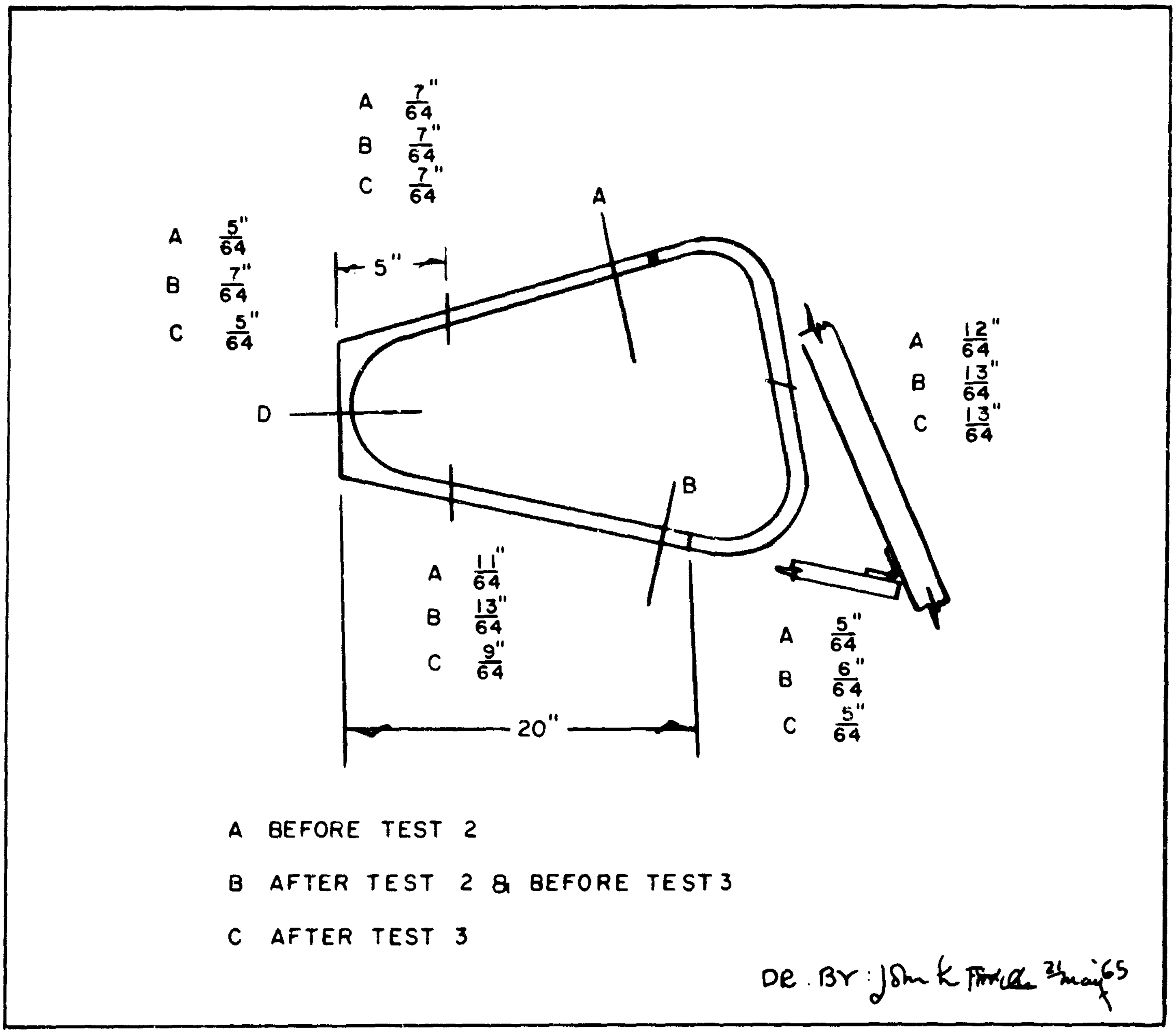

Figure 8. X-20 Window Gaps

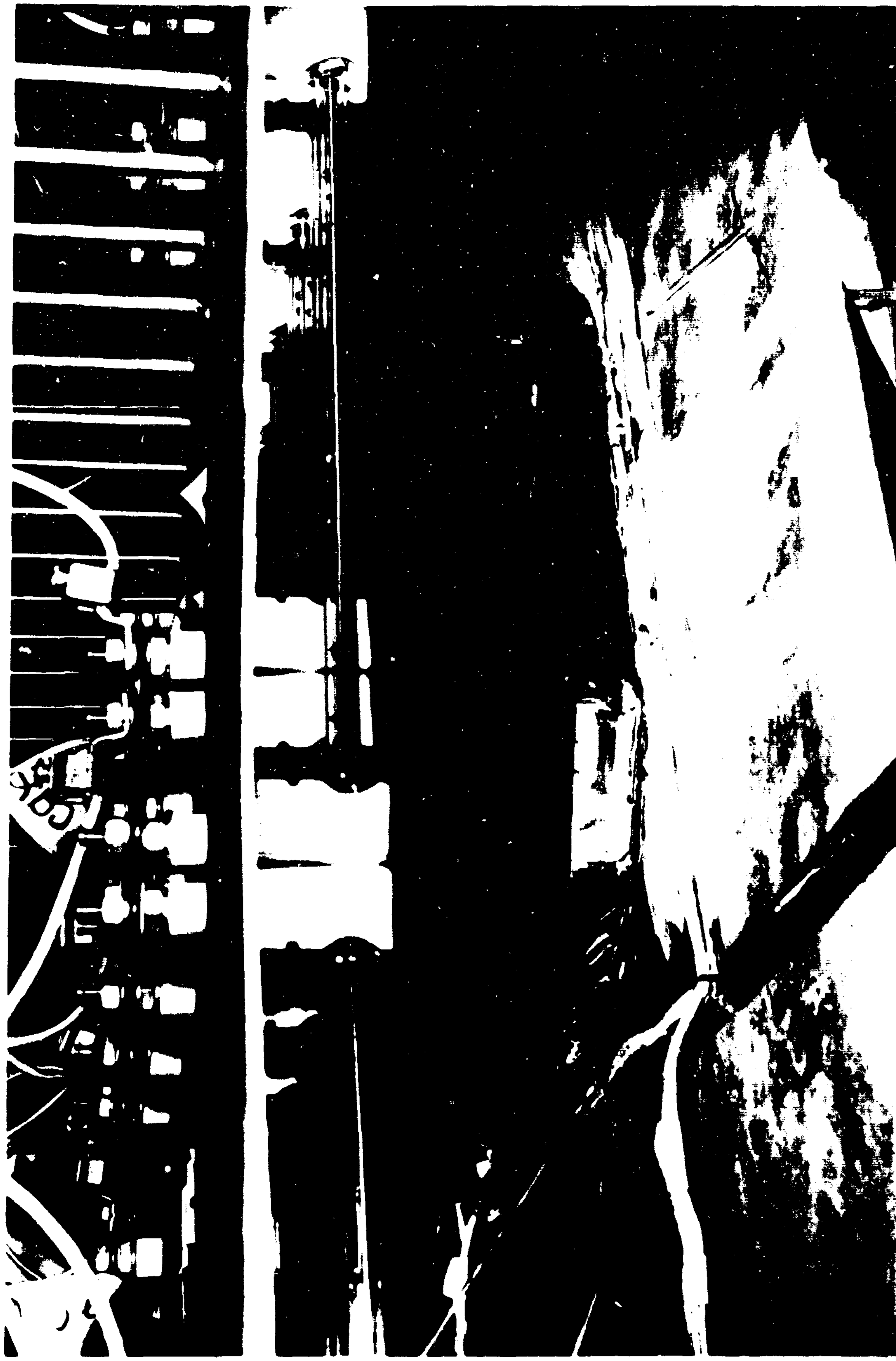

Figure 9. Failed Glass After Test Condition No. 3, X-20 Side Window

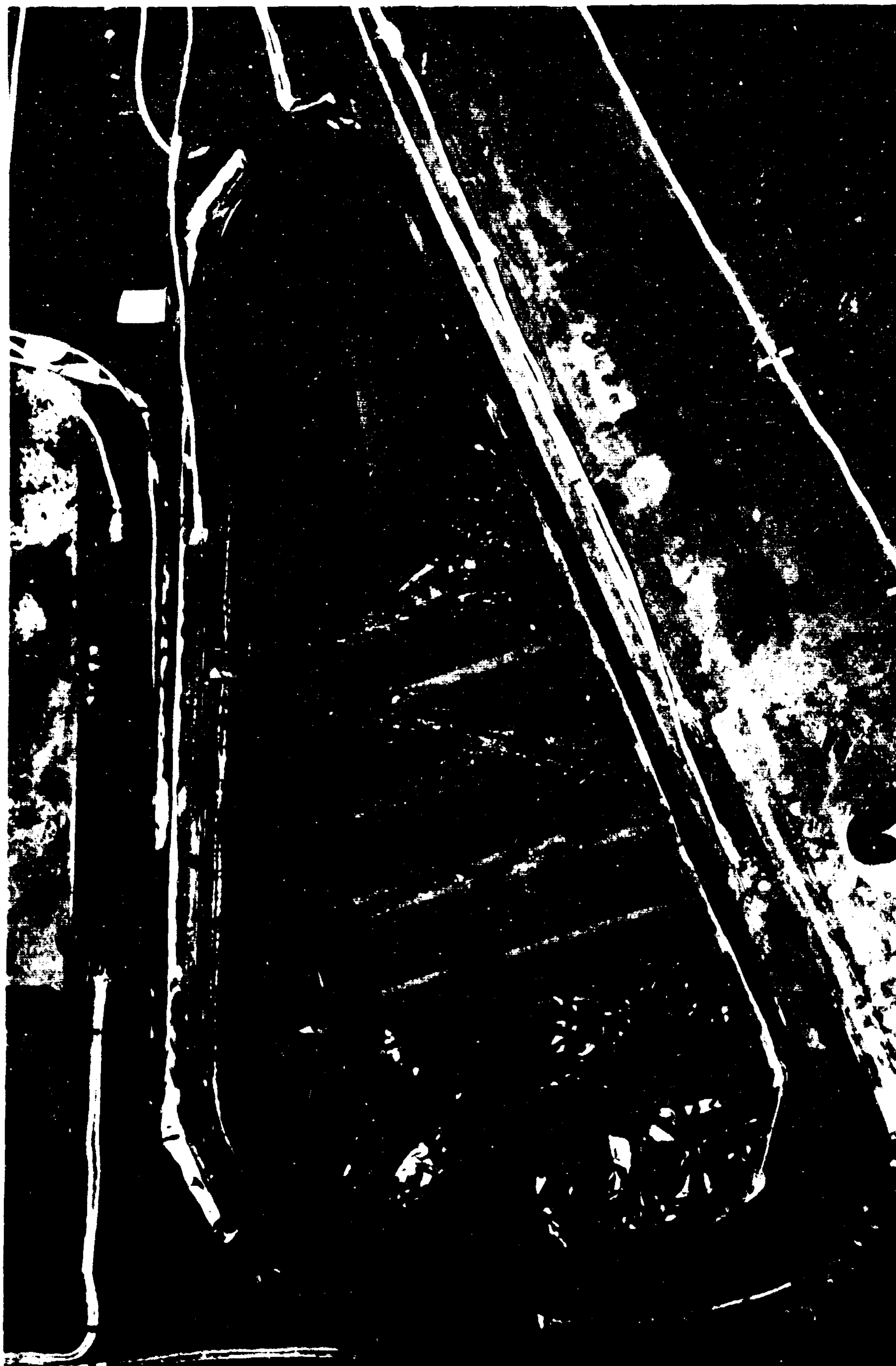

Figure 10. Failed Glass After Test Condition No. 3, X-20 Side Window

Figure 11. Failed Glass After Test Condition No. 3, X-20 Side Window

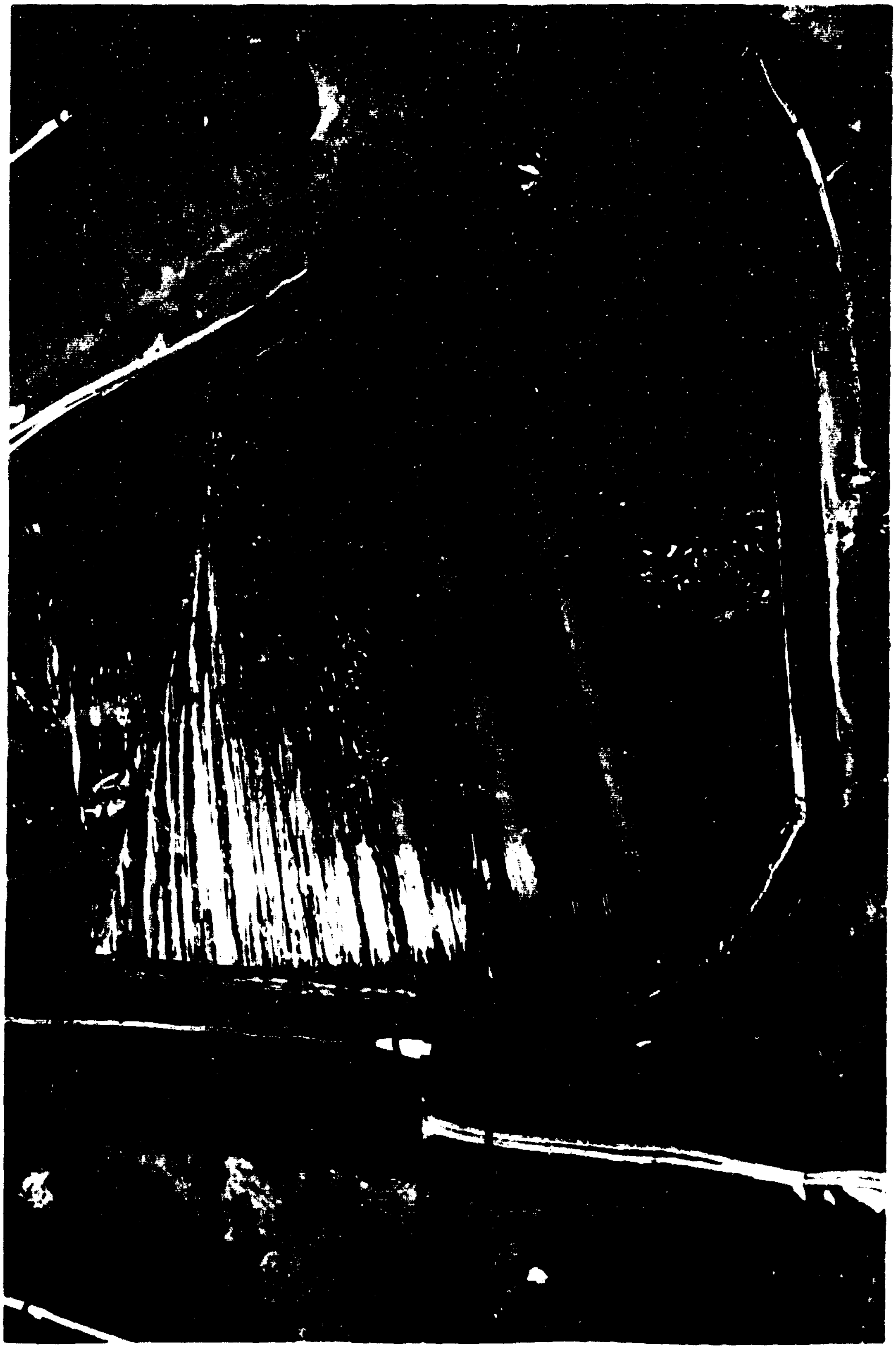

Figure 12. Failed Glass After Test Condition No. 3, X-20 Side Window

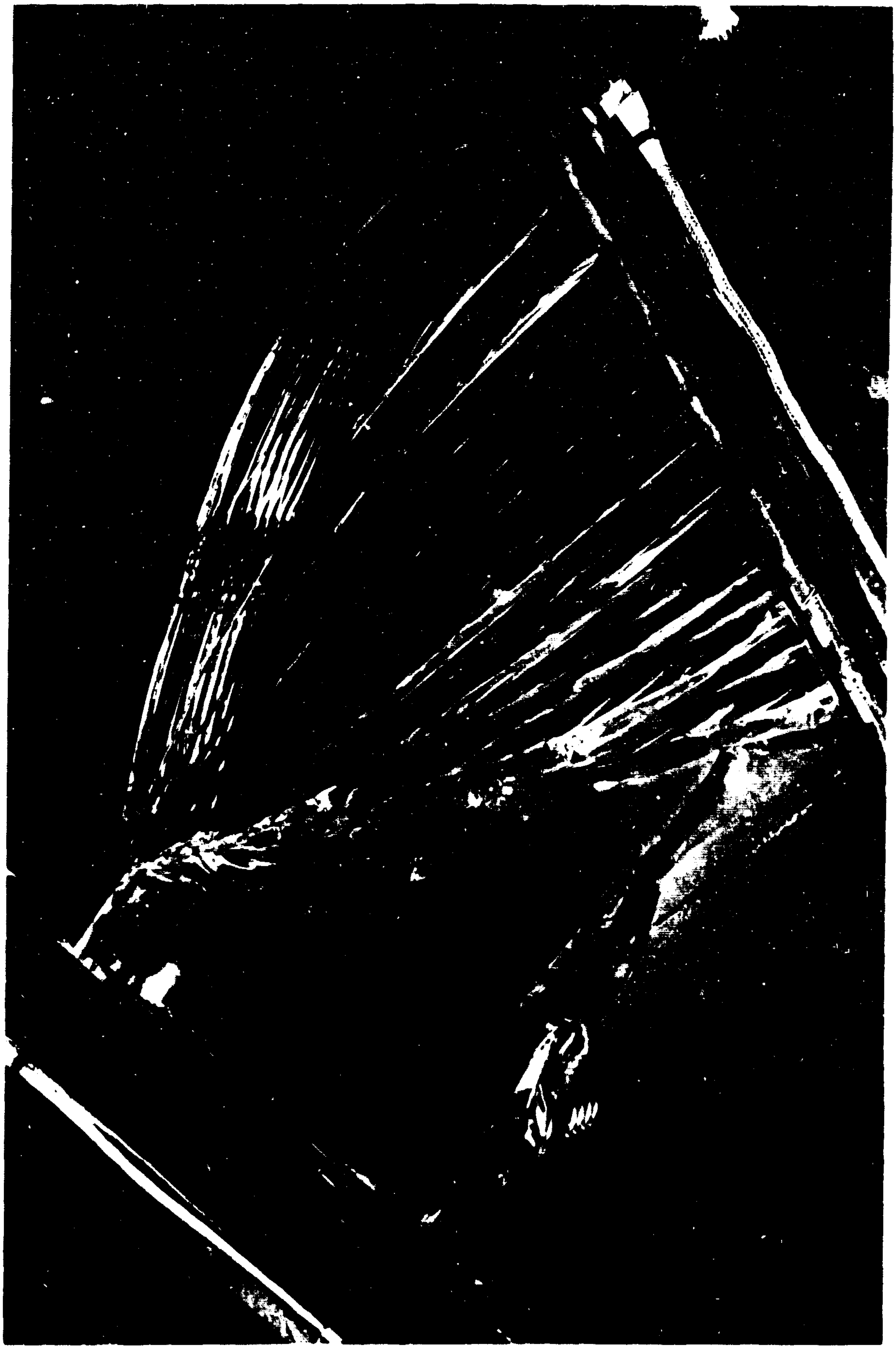

Figure 13. Failed Glass After Test Condition No. 3, X-20 Side Window

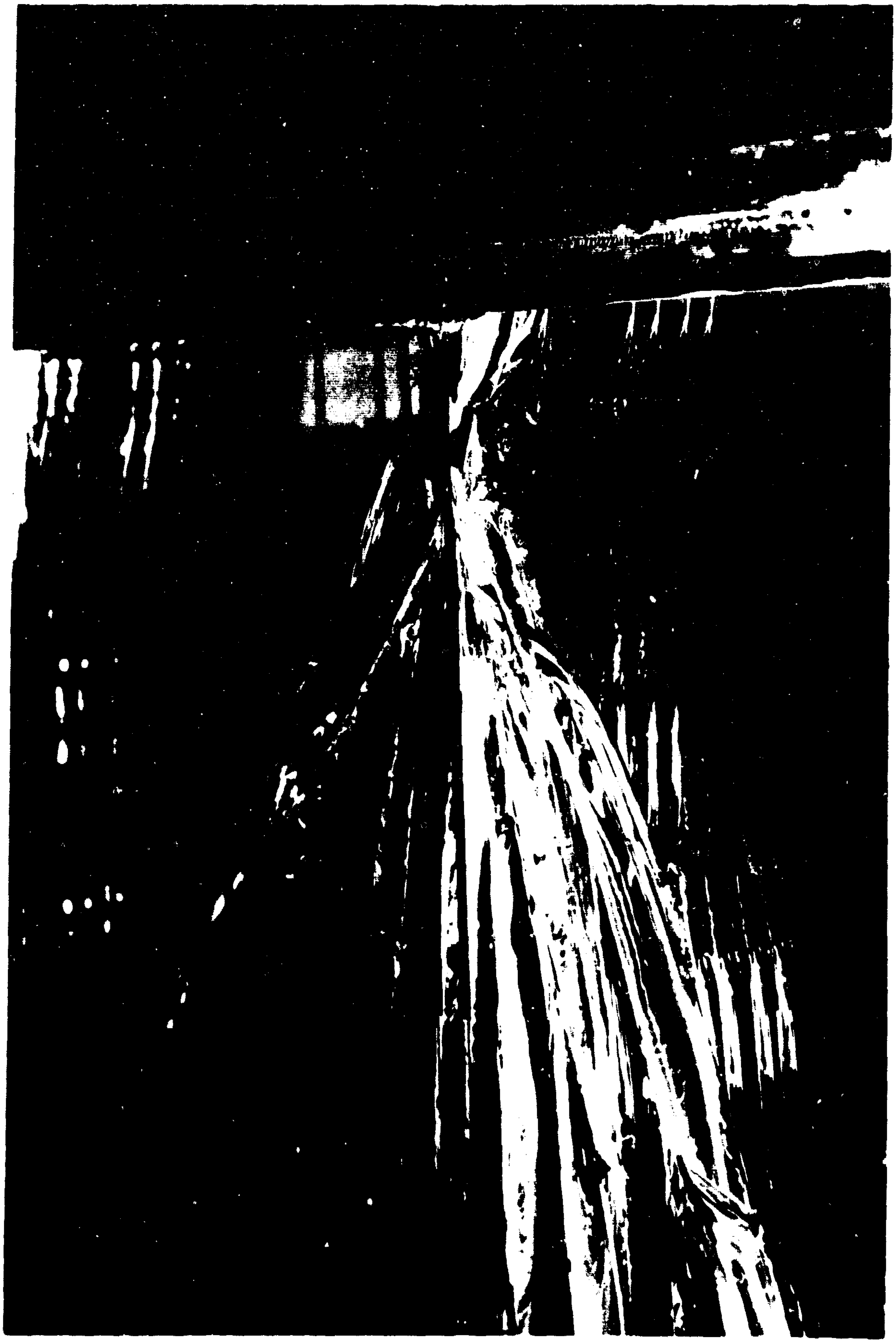

Figure 14. Failed Glass After Test Condition No. 3, X-20 Side Window

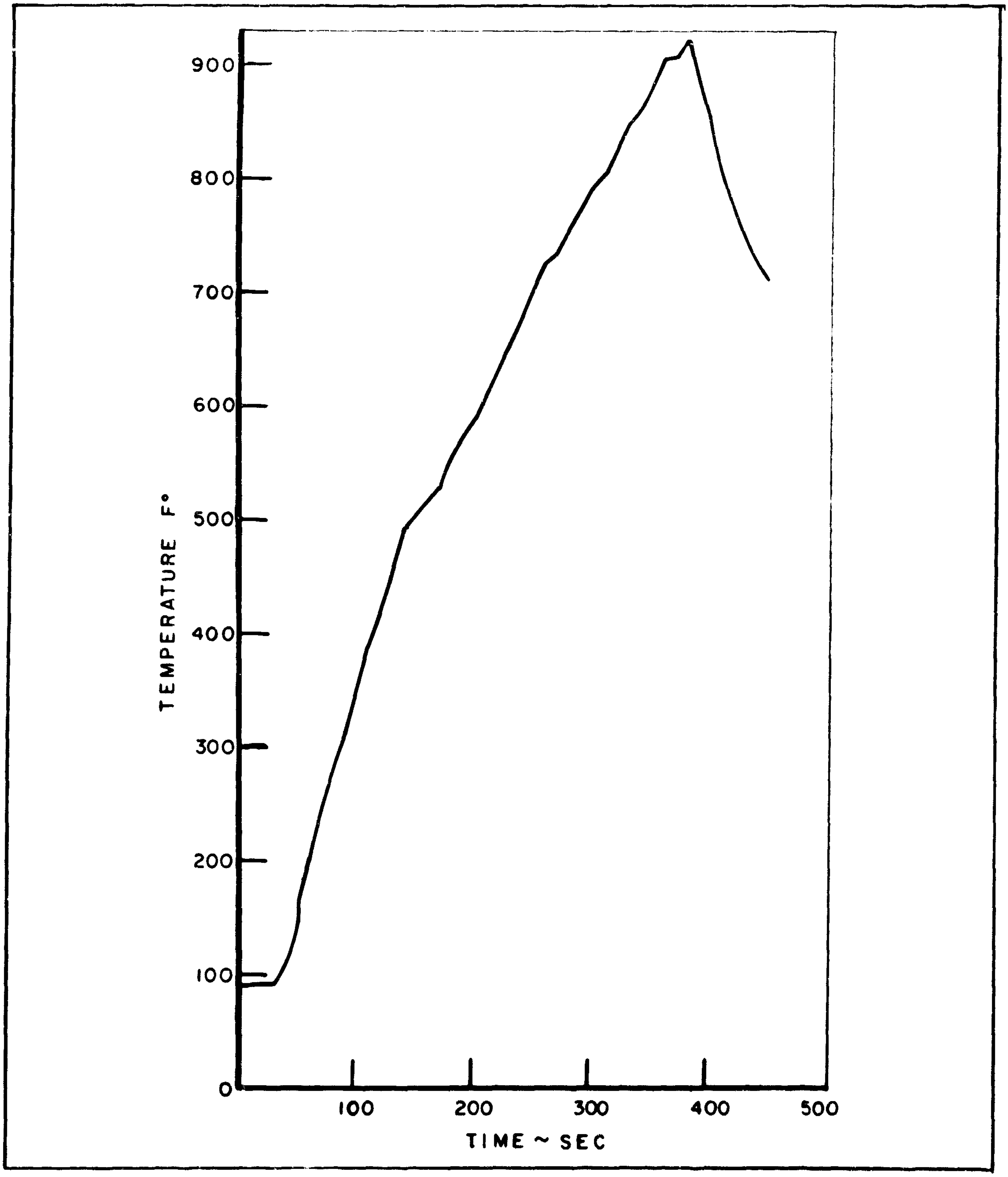

Figure 15. Thermocouple No. T3, Test Condition No. 3

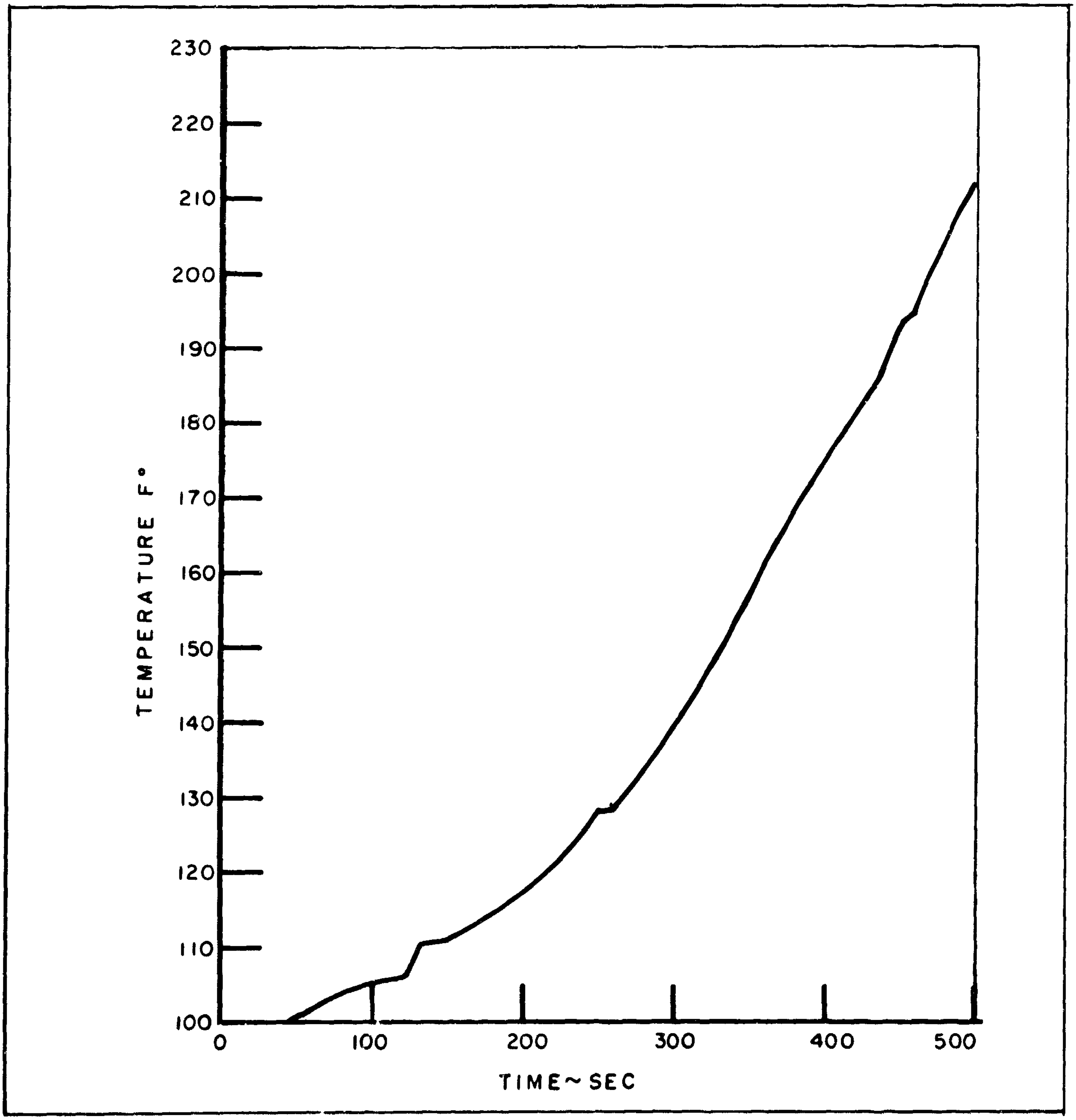

Figure 16. Thermocouple No. T5, Test Condition No. 3

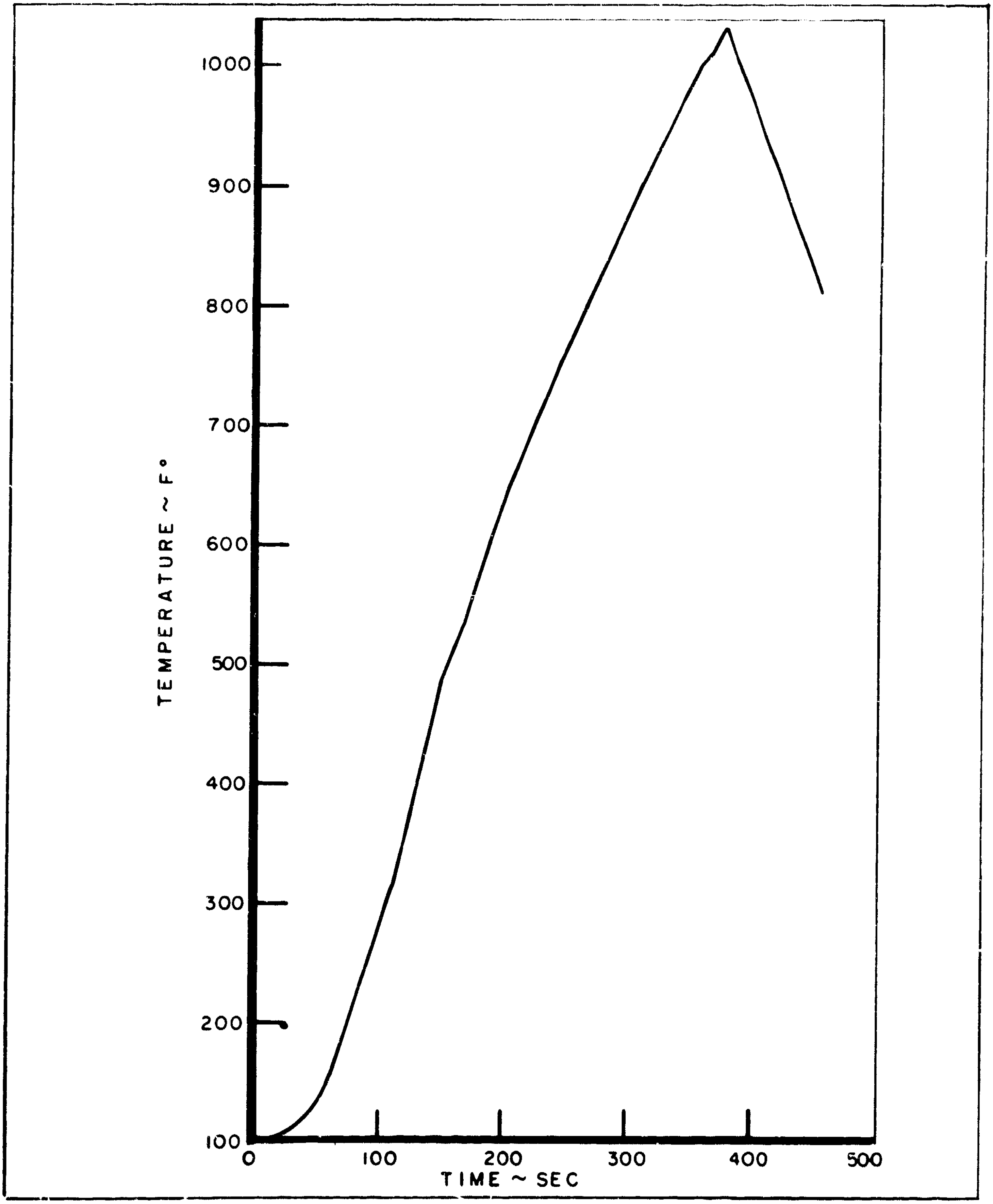

Figure 17. Thermocouple No. T16, Test Condition No. 3

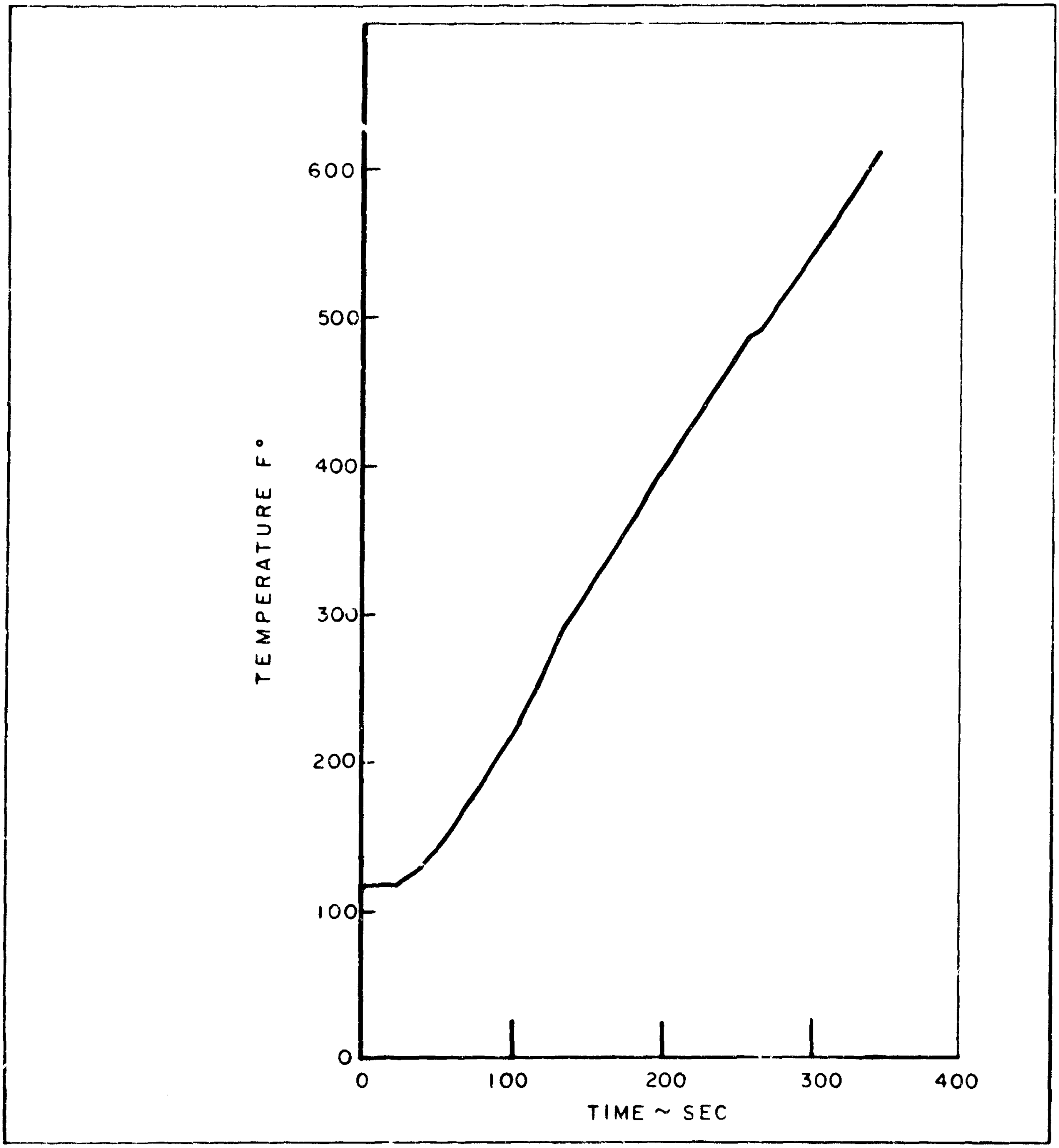

Figure 18. Thermistor No. TM-1, Test Condition No. 3

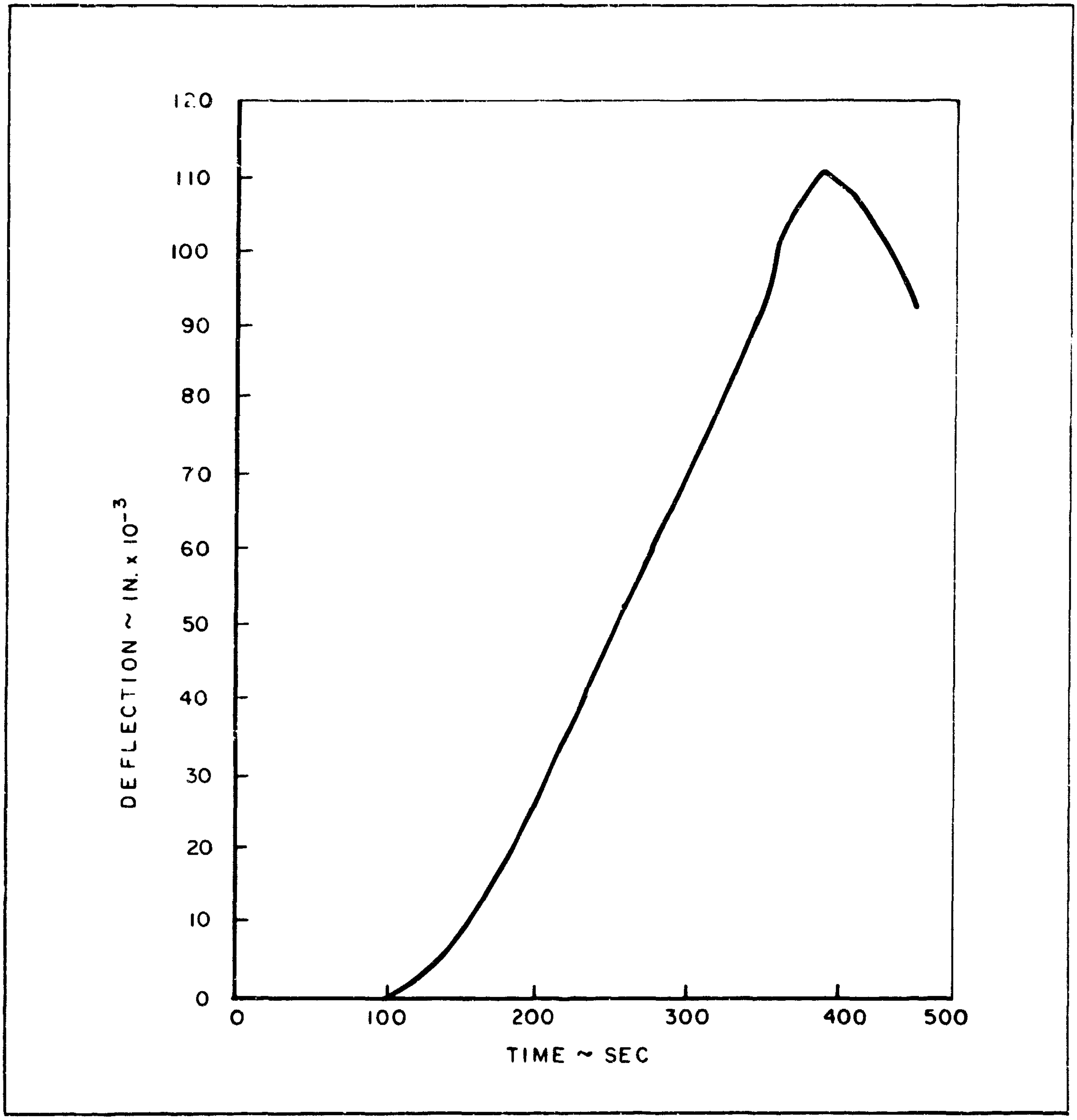

Figure 19. Deflection Rod No. DB5, Test Condition No. 3

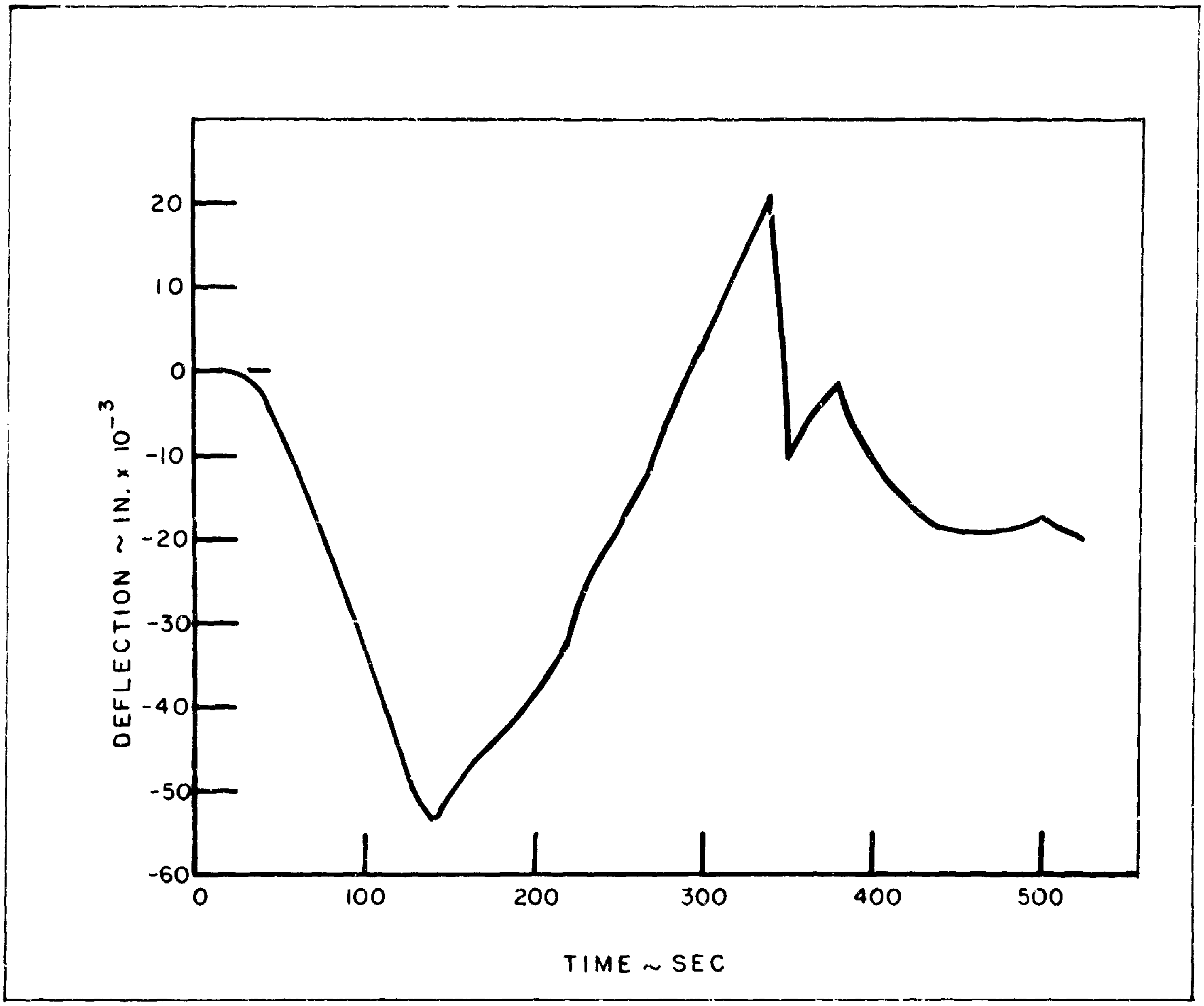

Figure 20. Deflection Rod No. DC2, Test Condition No. 3

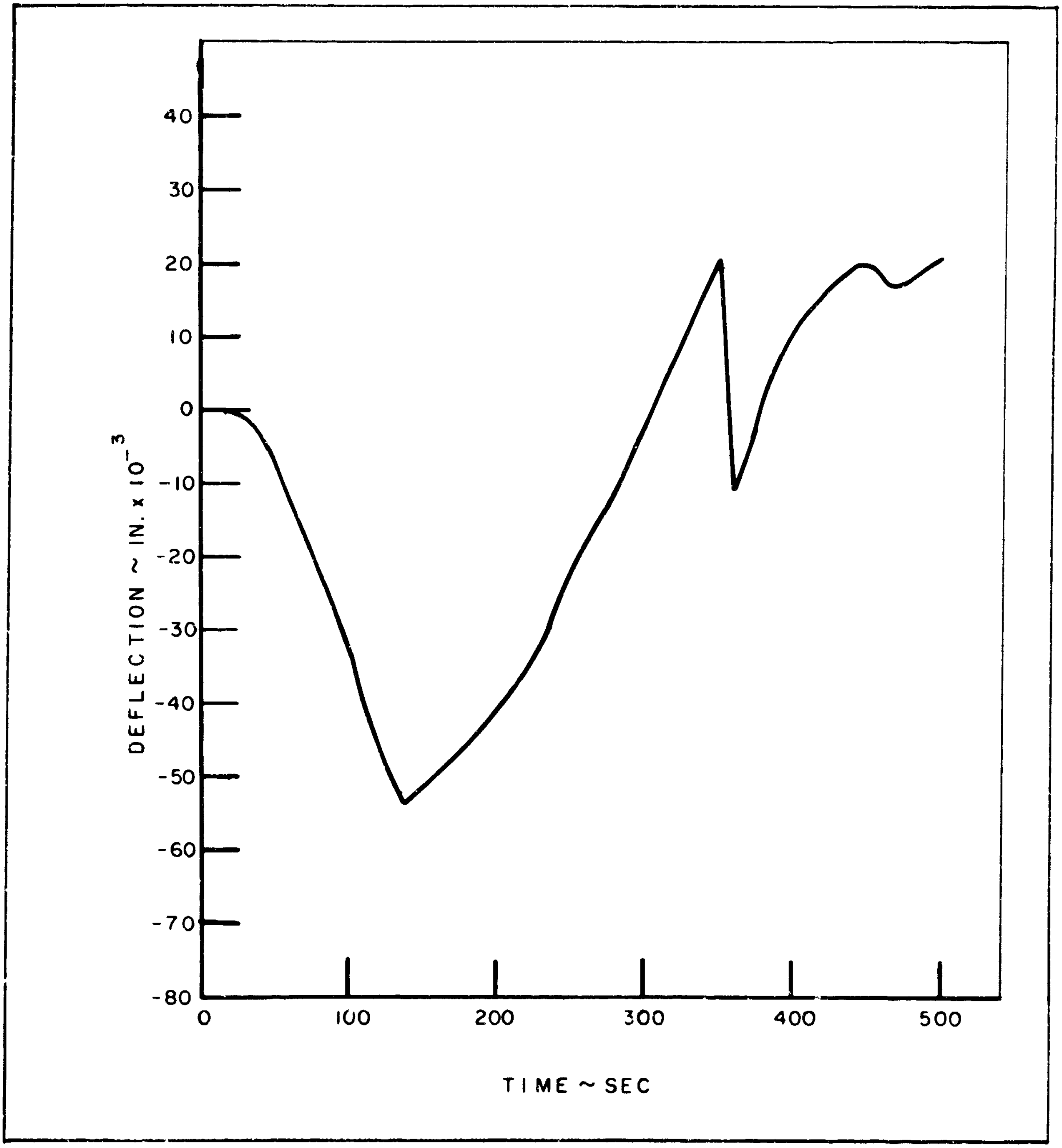

Figure 21. Deflection Rod No. DC3, Test Condition No. 3

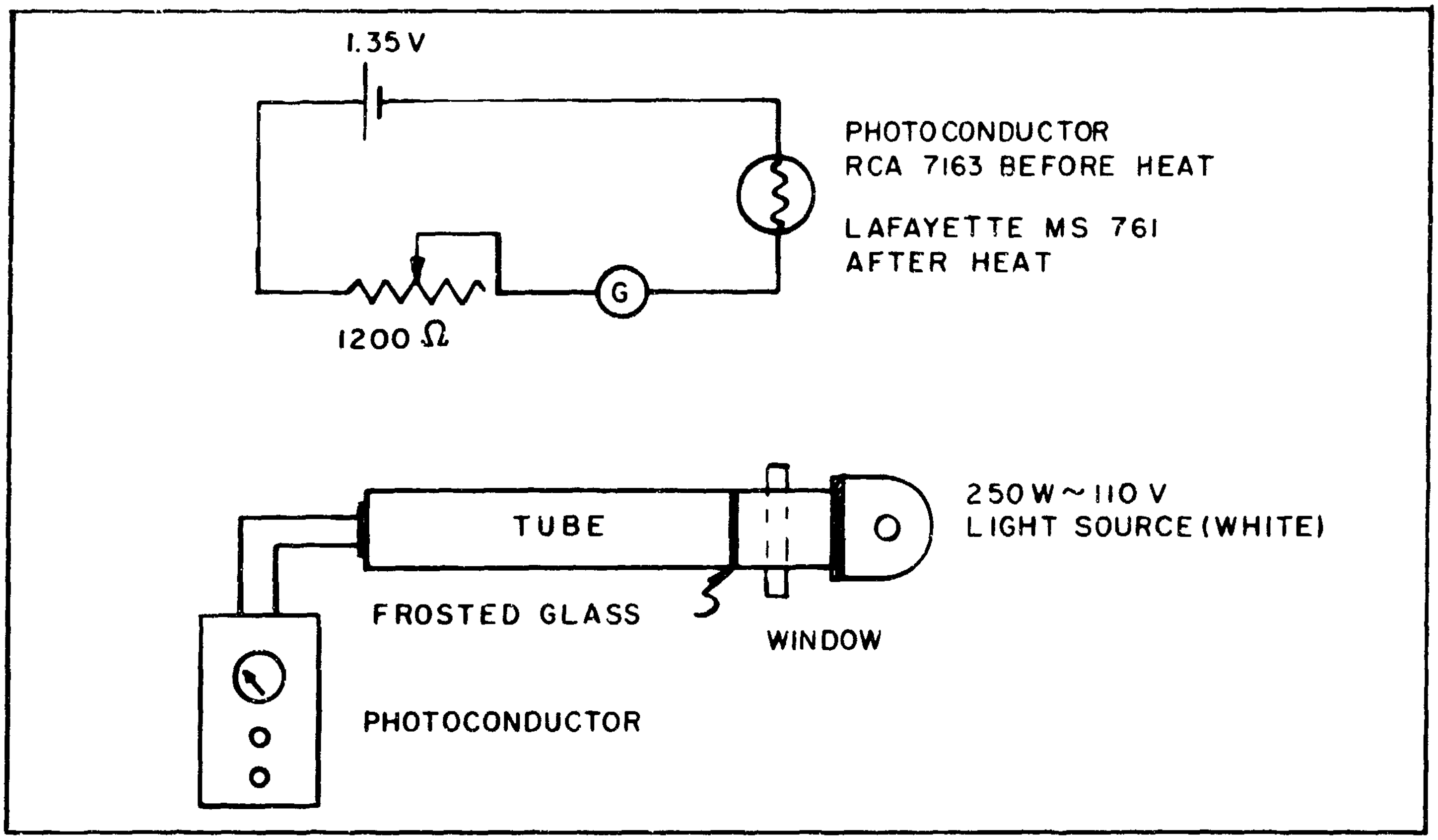

Figure 22. FDTT Light Transmission Apparatus

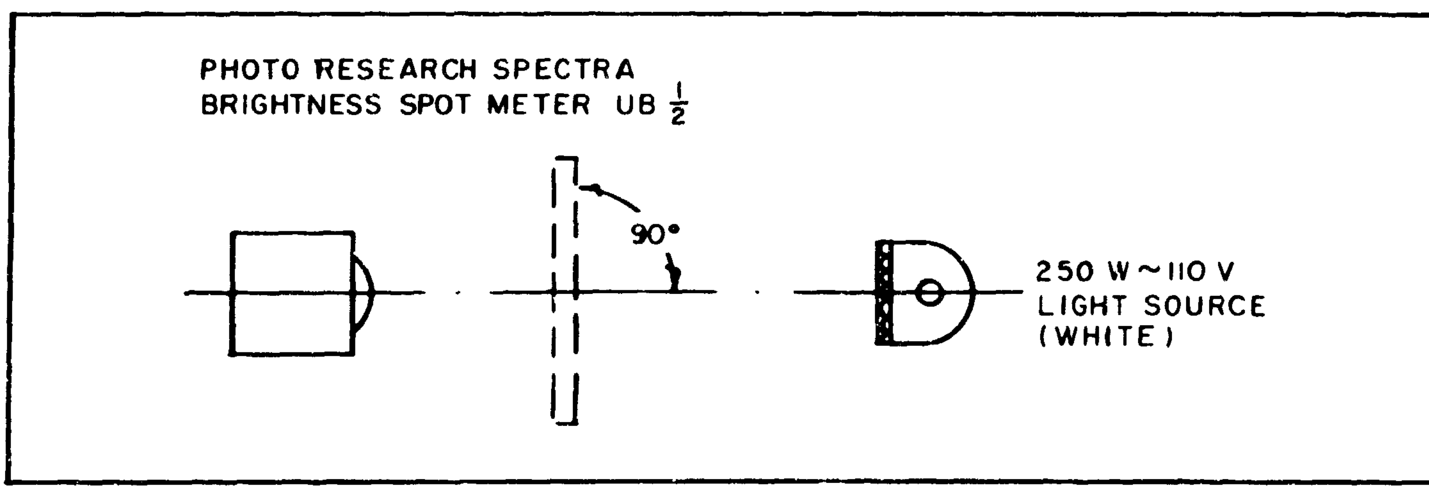

Figure 23. Standard Light Transmission Apparatus

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13 ABSTRACT

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